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Impacts of climate shifts in the late 20th century on zooplankton and fishery resources in the Japan Sea

Goals:

- to find significant correlations between changes of environments and biotic components of the Japan Sea ecosystem

- to reveal mechanisms of these relations (mainly by analyzing of temporal lags)

- to trace the ecosystem response on climate regime shift in the late 1980s

- to elaborate a conceptual model of the climate changes influence on the Japan Sea ecosystem

Materials:

Climatic indices:

- Siberian High Index: mean atmospheric pressure in the area 40-65 N 80-120 E averaged for December- February (*Panagiotopoulos et al., 2005*);

- Pressure gradient between the centers of Siberian High and Aleutian Low, by months (*Vasilevskaya et al., 2003*);

- Aleutian Low Pressure Index (ALPI),
- North Pacific Index (NPI),
- West Pacific Index (WP),
- Pacific Decadal Oscillation (PDO),
- Victoria winter Pattern (after *Bond et al, 2003*),
- Arctic Oscillation Index (AO),
- El Nino – South Oscillation Index (ENSO)

(from http://www.cdc.noaa.gov/ClimateIndices/ ,
http://www.beringclimate.noaa.gov/data/index.php ,
http://www.cgd.ucar.edu/cas/catalog/climind/,
http://www.cpc.ncep.noaa.gov/products/ ,
http://jisao.washington.edu/ ,
http://www.pac.dfo-mpo.gc.ca/sci/sa-mfpd/climate/clm_index.htm)

Materials:

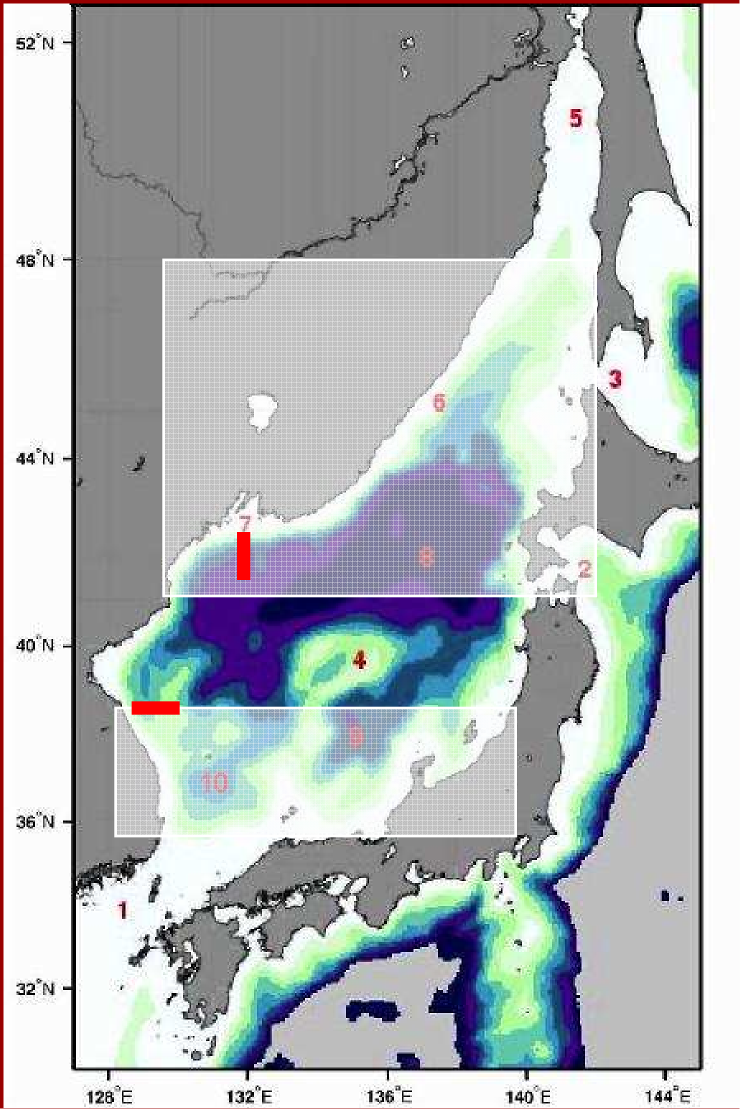
Water temperature data:

- Monthly SST anomalies data provided by the Japan Meteorological Agency (JMA) averaged seasonally for the zones 35-38 N (southern part of the Japan Sea) and 41-45 N (northern part of the Japan Sea) (since 1950)

- Seasonal anomalies of the mean temperatures of the surface and subsurface layers at the standard section $41^{o}30$-$42^{o}30$ N $132^{o}00$ E (since 1926 - *authors data*)

- Seasonal anomalies of the mean temperature at 200 m depth at the standard section L-107 (38^{o} N $128^{o}26$-$129^{o}25$ E) calculated from the data provided by Korean Oceanographic Data Center (KODC) (since 1955)

Note: the Intermediate Water mass occupies the subsurface layer in the northwestern Japan Sea



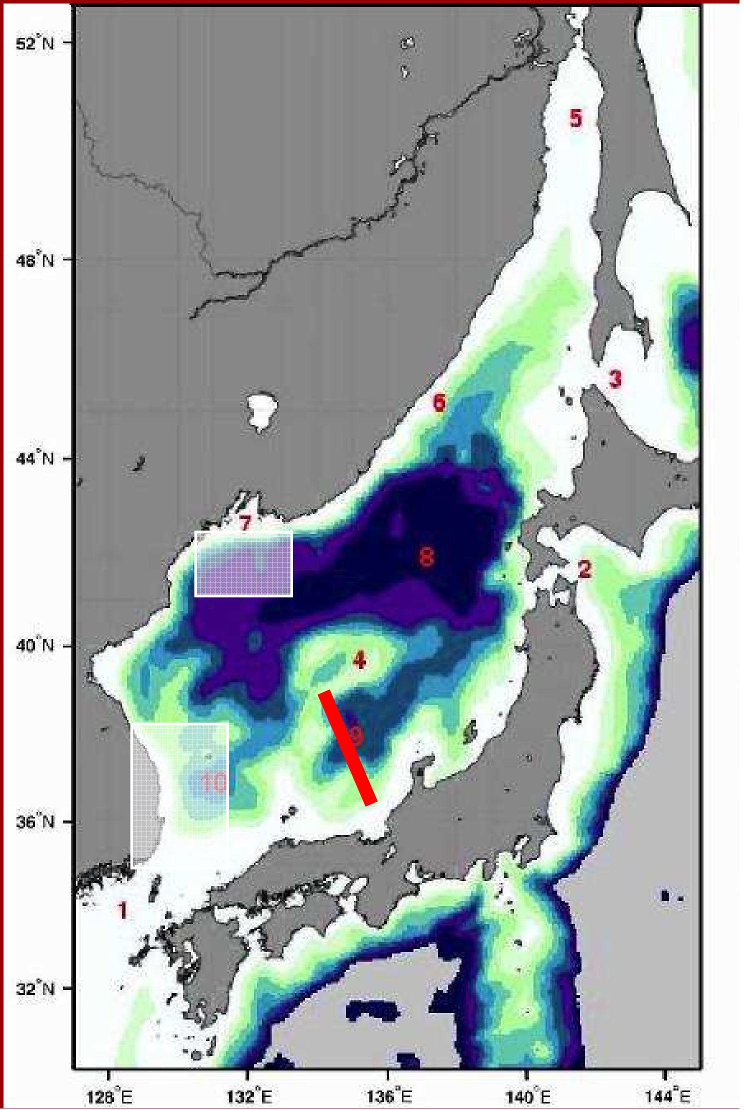
Materials:

Zooplankton data:

- Mean seasonal anomalies of the total biomass of zooplankton at 6 stations of the standard PM-line section, annually averaged (for 1973-1995 - from *Minami, 1999; Iguchi, 2004*)

- Annual data on the mean total biomass of zooplankton in the EEZ of South Korea (since 1962 - after *S. Kang et al., 2000, with additions of Y.-S. Kang and the latest additions from KODC site*)

- Mean total biomass of zooplankton in 41-42 N 131-133 E averaged for May-June of each year (since 1989 - *authors data*)



Materials:

Fish and squids data:

- Annual catch of sardine by Japan, S. Korea and Russia

- Annual catch of japanese common squid by Japan and S. Korea

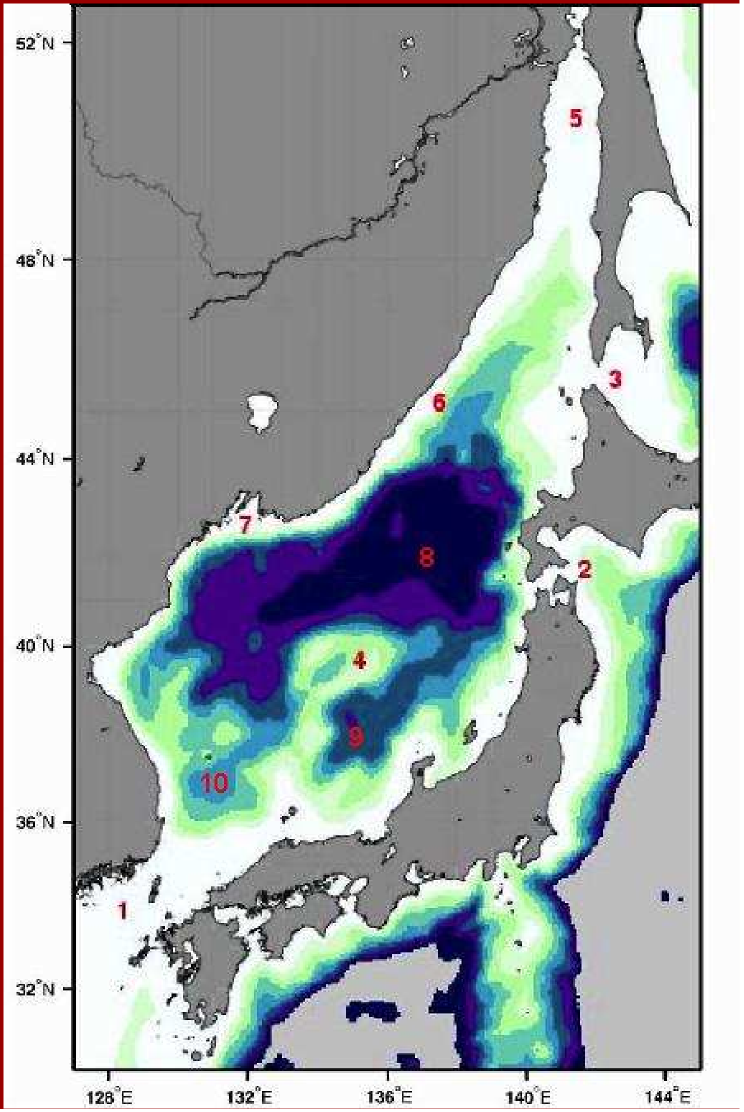
- Annual catch of chub mackerel by Japan, S. Korea and Russia

- Annual catch of saury by S. Korea

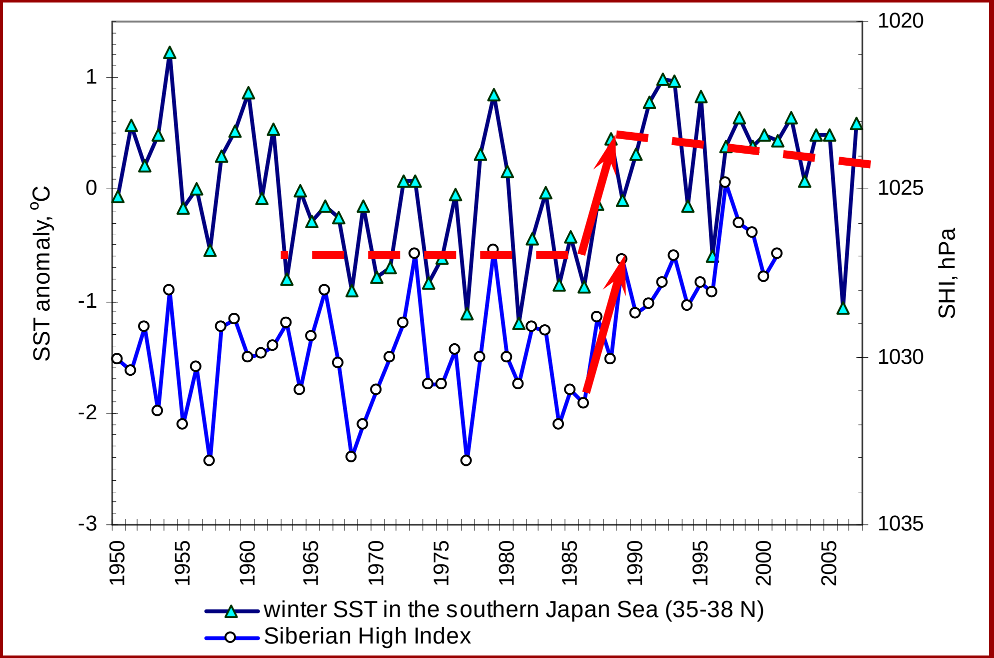
- Walleye pollock generations abundance in the northwestern Japan Sea

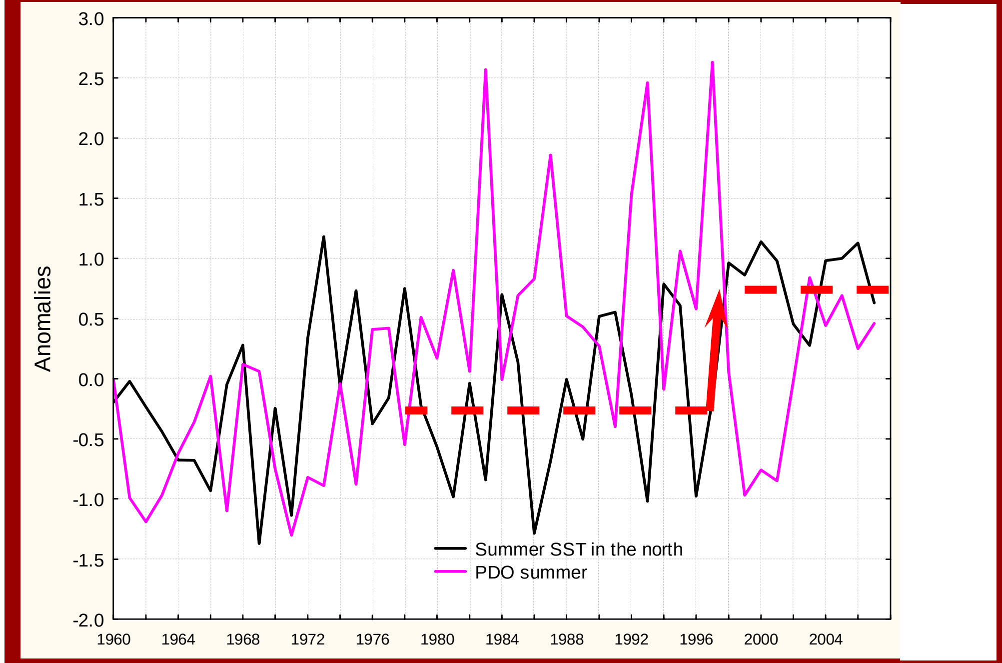
- Arabesque greenling biomass in the northwestern Japan Sea

- Annual catch of saffron cod in the northwestern Japan Sea



Sea Surface Temperature:





Winter SST has the best correlations with:

- in the northern Japan Sea – with the pressure gradient between Siberian High and Aleutian Low in December (positive, quasi-synchronous)

- in the southern Japan Sea – with the Siberian High Index (negative, synchronous; **R = -0.54,** after 3-years smoothing **R = -0.74**)

Mechanism of relation: sea surface cooling by cold and dry winter monsoon winds.

The Siberian High weakening in 1986-1989 caused (directly or through the weak gradient) SST rise in 1986-1989, with further partial relaxation

Summer SST in the Japan Sea have the best correlations with the summer PDO (negative, synchronous). However, PDO is the index describing SST fluctuations in the North Pacific. Stable significant correlations (R > 0.5) with any atmospheric indices were not found.

The climate regime shift of 1986-1989 is not obvious for summer SST.

Subsurface temperature:

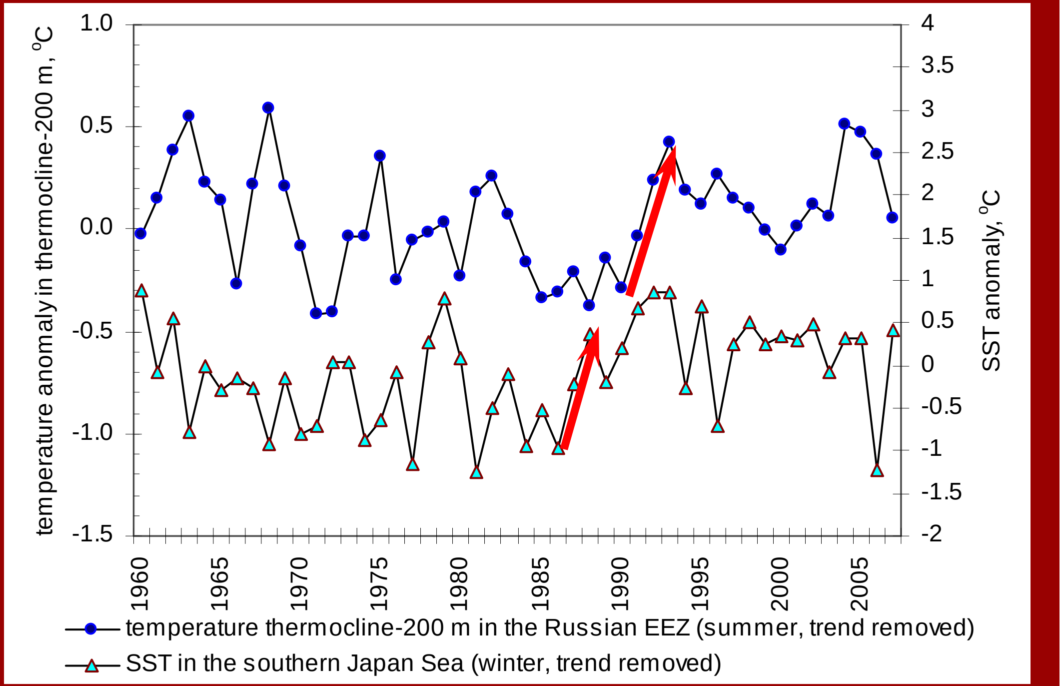
Temperature in the subsurface layer has the best correlation with the winter SST in the southern part of the Japan Sea.

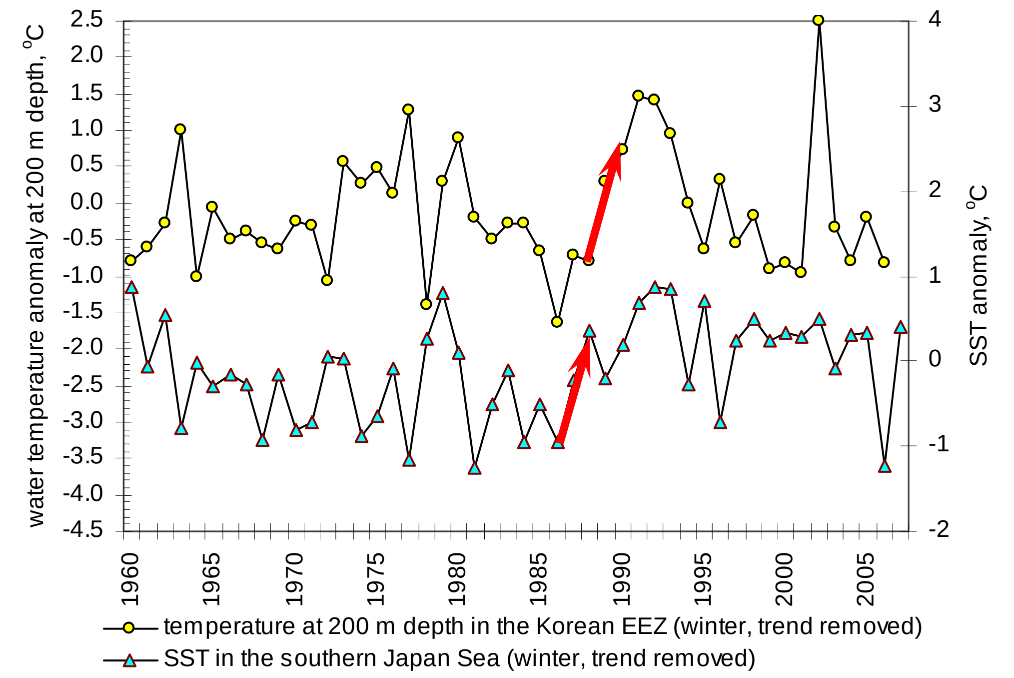
In the Russian EEZ the correlation is positive, with 3 years lag (**R = 0.42**, after smoothing **R = 0.62**).
In the Korean EEZ the correlation is positive, with 1 year lag (**R = 0.48**, after smoothing **R = 0.58**).

Thus, the mechanism of the Intermediate Water formation in the process of subduction at the south periphery of the Subarctic Front prevails in the Japan Sea.

If that, the lags 1 year for the Korean zone and 3 years for the Russian zone are determined by the time of transfer new portions of the Intermediate Water from the main area of formation to these areas. This succession of renovation shows an anti-cyclonic circulation of the Intermediate Water mass in the Japan Sea.

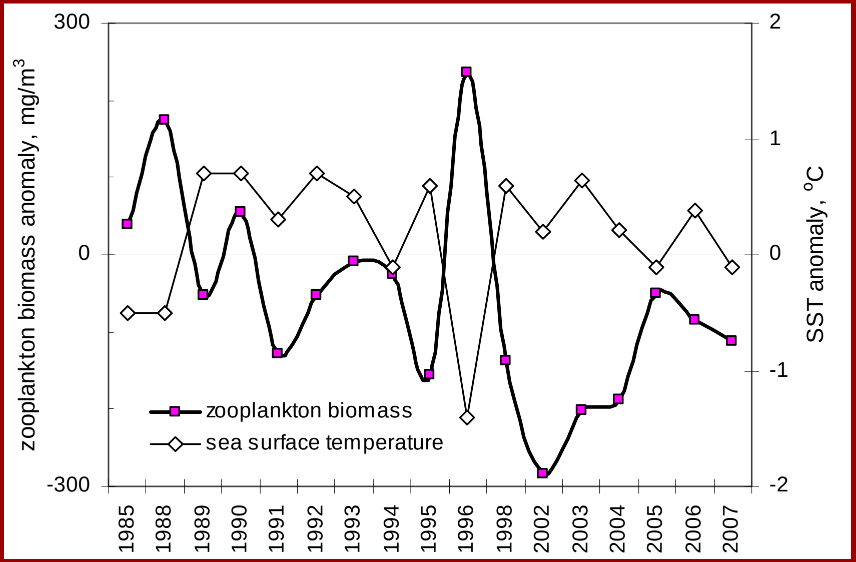
SST increasing in 1986-1989 caused the subsurface temperature increasing in the Korean zone in 1988-1990, and in the Russian zone – in 1990-1993.



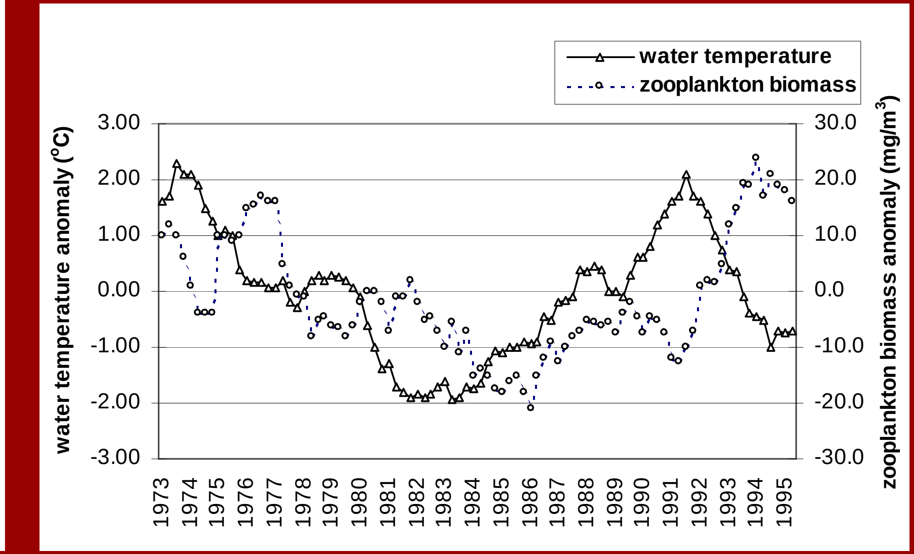


Zooplankton:

Negative dependence on spring-summer SST is well-known. It is based on the primary production negative dependence on thermal stratification.



Dolganova, Zuenko, 2004, with additions



Minami, 1999; modified by Iguchi, 2004

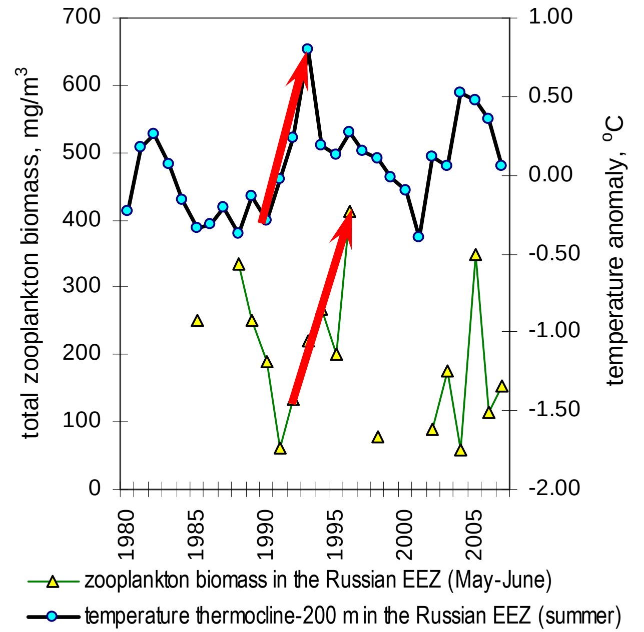
However, this correlation could be found for year-to-year scale only, but positive relation typical for decadal scale was not described yet.

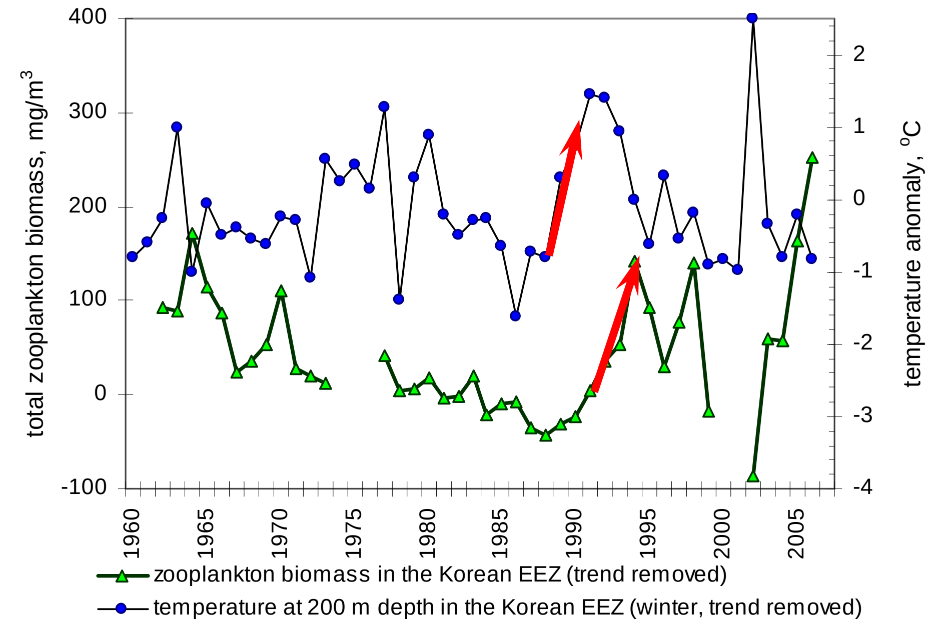
Zooplankton:

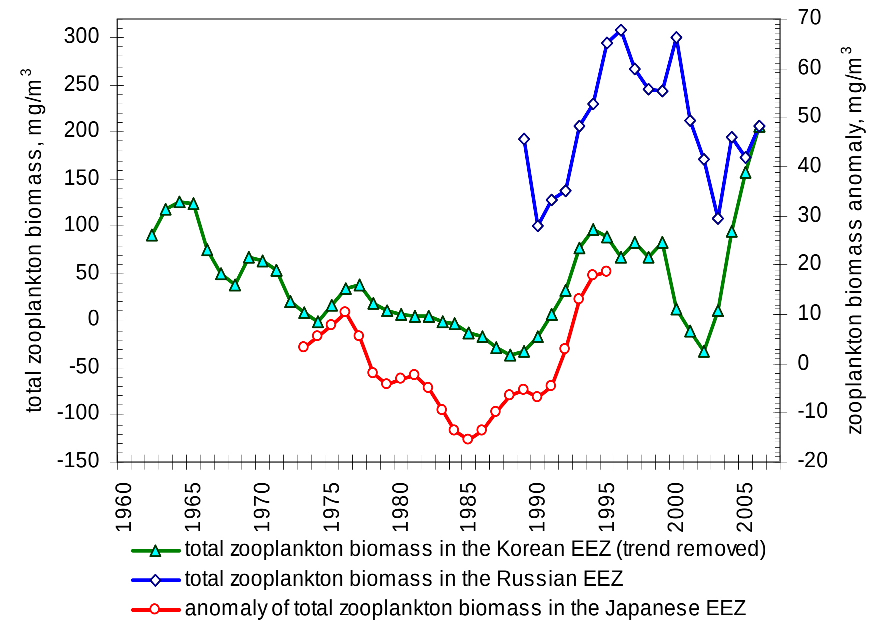
The highest correlations (positive) were found between total biomass of zooplankton and subsurface temperature.

In the Russian zone R = 0.70, after smoothing **R = 0,84**, with lag 3 years.
In the Korean zone R = 0.32, after smoothing **R = 0,50**, with lag 3 years.
In the Japanese zone we have no data on subsurface temperature, but the total biomass of zooplankton correlated well with the subsurface temperature in the Korean and Russian zones.

Zooplankton biomasses in all 3 zones are well correlated, with small shifts in the succession: **Japan-Korea-Russia** (that corresponds to the anti-cyclonic circulation of the Intermediate Water mass).

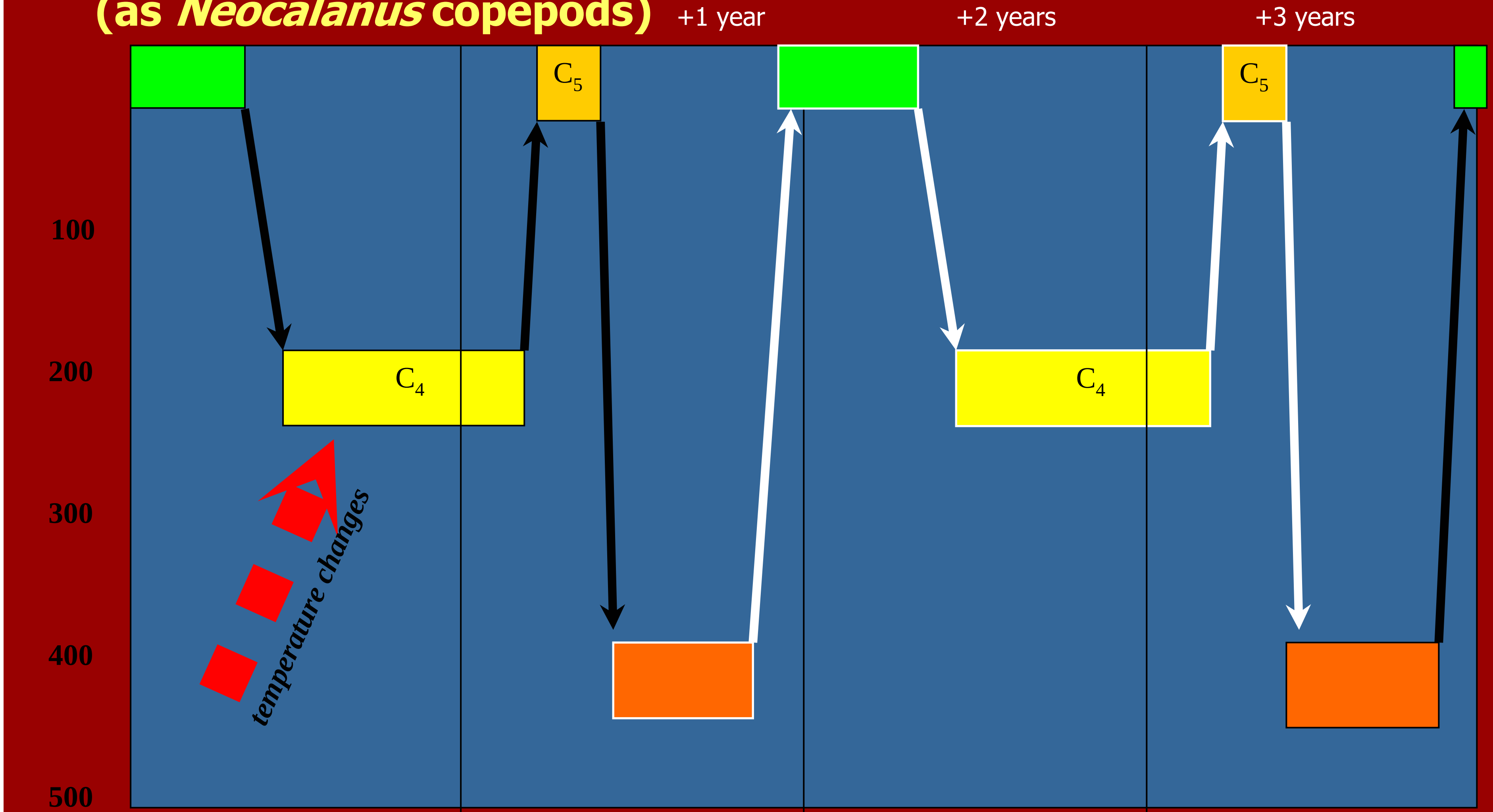






smoothed by 3-years running smoothing

Proposed mechanism of water temperature in the subsurface layer influence on zooplankton species with 2-years life cycle (as *Neocalanus* copepods)



period of the sub-surface temperature influence on copepods maturing

this influence is not essential for the current (parental) generation

success of reproduction and number of recruits depend on this influence, although their biomass is insignificant

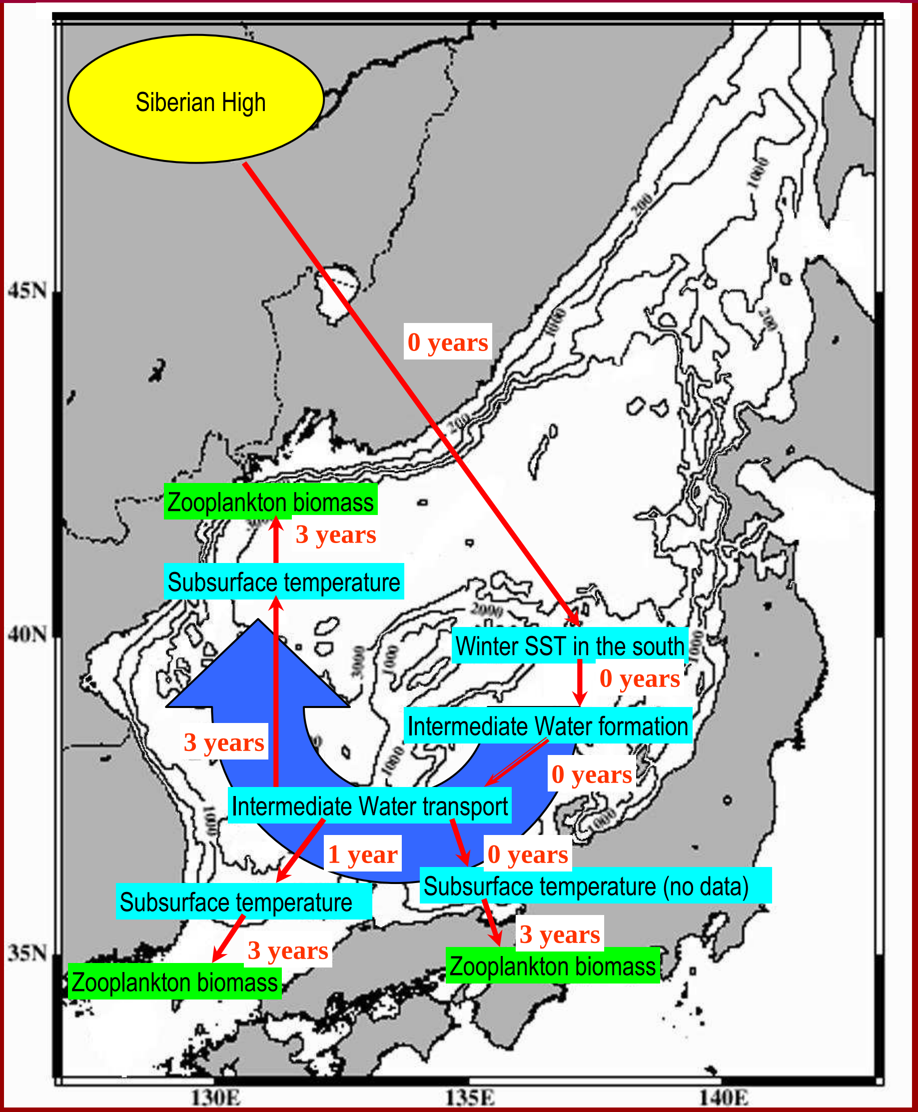
the effect on biomass will appear when the recruits will grew to the stage C5, i.e. in the 3th years after the impact

Scheme of climate change influence on zooplankton abundance in the Japan Sea

Atmospheric conditions influence on winter SST by means of air-sea heat exchange dependent on the rate of winter monsoon winds.

Winter SST influence on the subsurface temperature because the Intermediate Water forms in winter in by the process of surface water subduction. New formed portions of this water mass are transported from the formation area by anti-cyclonic circulation (not observed directly yet).

Subsurface temperature influence on the process of mass Copepoda species maturation during their dormancy at the depth, that is important for the next generation and appears in the recruits biomass with the time lag 3 years.



Siberian High

0 years

Winter SST in the south

0 years

Intermediate Water formation

0 years

Intermediate Water transport

3 years

Subsurface temperature

3 years

Zooplankton biomass

1 year

Subsurface temperature

3 years

Zooplankton biomass

0 years

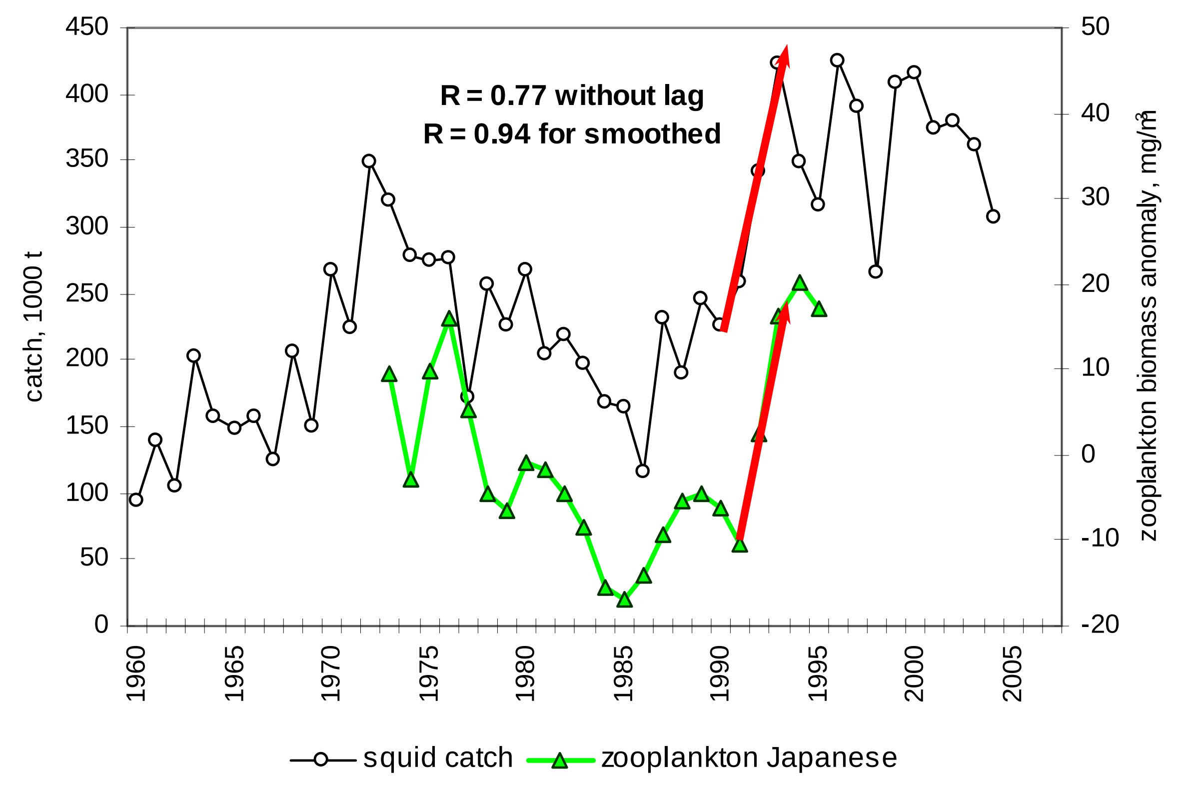
Subsurface temperature (no data)

3 years

Zooplankton biomass

Japanese common squid:

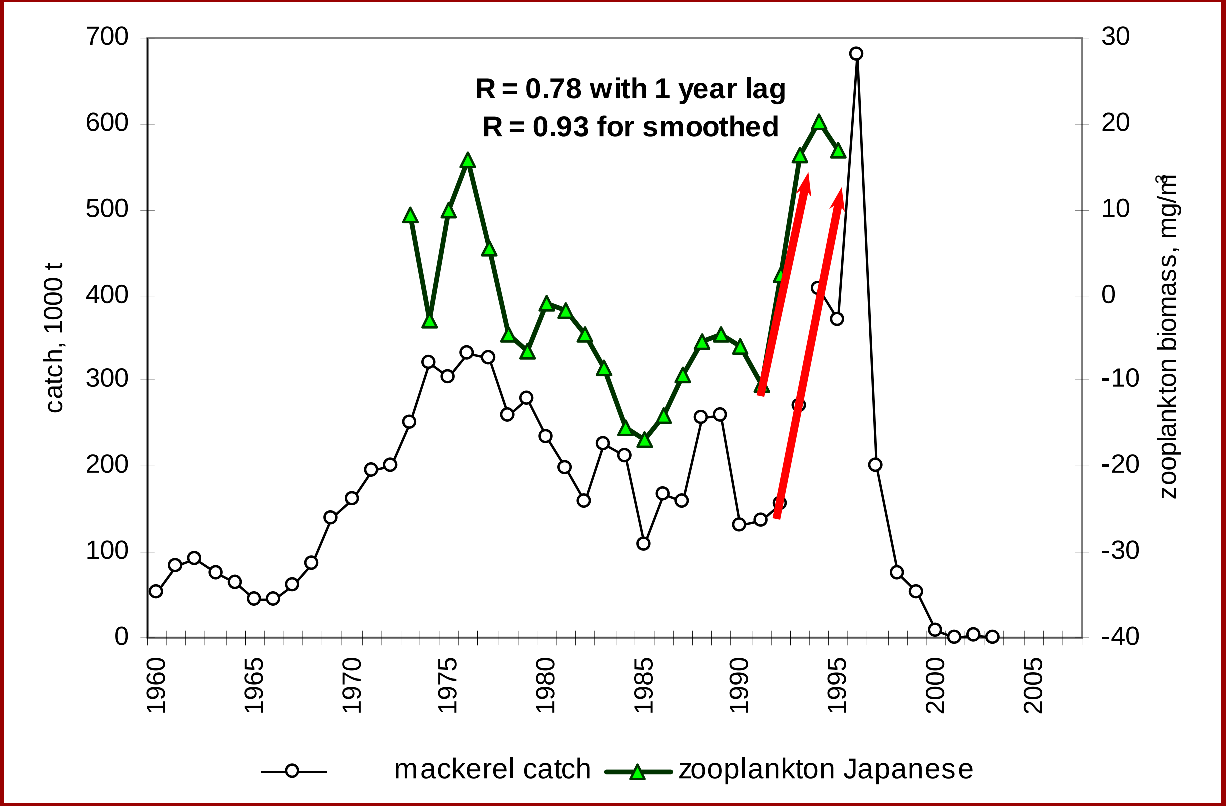
Annual catch of the squid correlates well with zooplankton biomass in the Japanese zone (positive, synchronous)



Rise of zooplankton abundance in 1991-1993 (after SST rising in 1986-1989) became the reason for the squid stock and catch increase in 1991-1993, with the possible mechanism of its paralarvae better survival.
Rrecently the squid is the main object of commercial fishery in the Japan Sea

The regime shift of the late 1990s has no visible consequences for the squid

Chub mackerel:



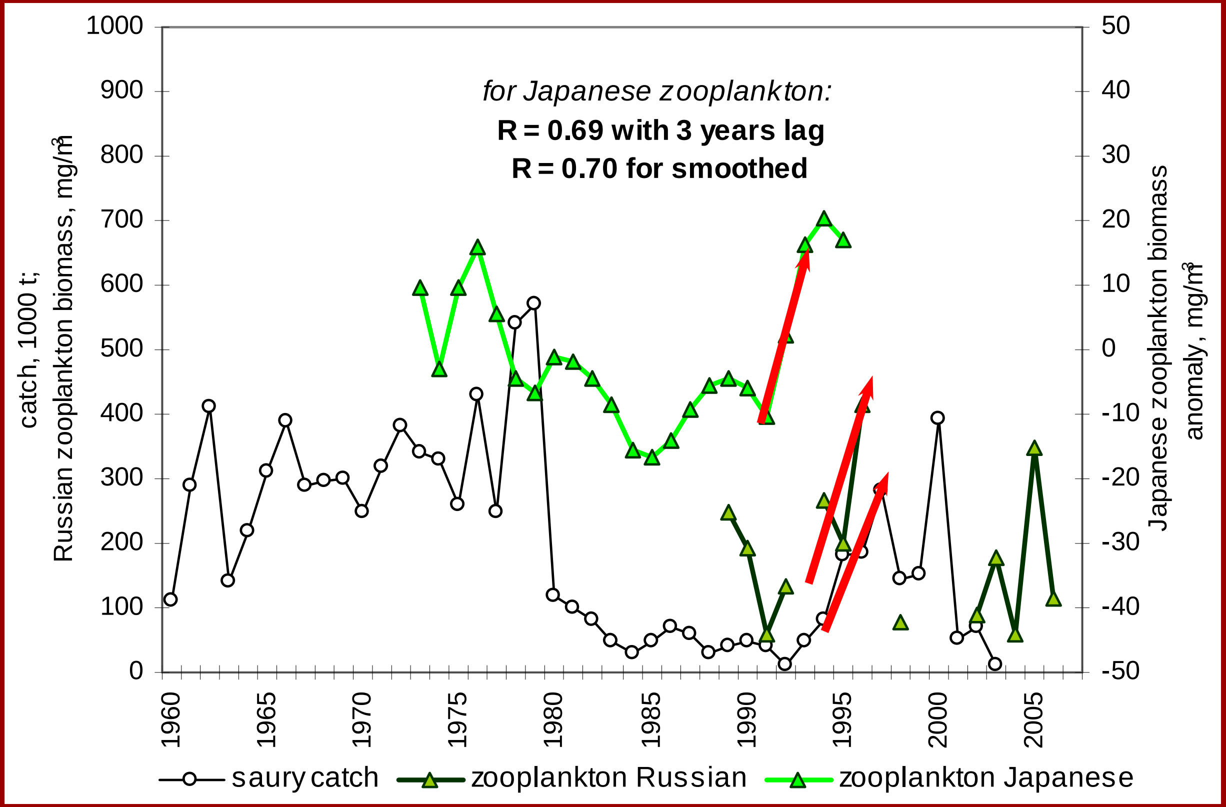
The mackerel catch correlates with zooplankton biomass in the Japanese zone, as well (positive, temporal lag 0-1 years).

The lag is too short for this long-living species, but it is reasoned by the considerable Japanese fishery of the young (1+) mackerel in the southern Japan Sea.

Rise of zooplankton abundance in 1991-1993 (after SST rising in 1986-1989) became the reason for the mackerel stock and catch increase, with possible mechanism of its larvae better survival.

The regime shift of the late 1990s has no visible consequences for the mackerel.

Pacific saury:



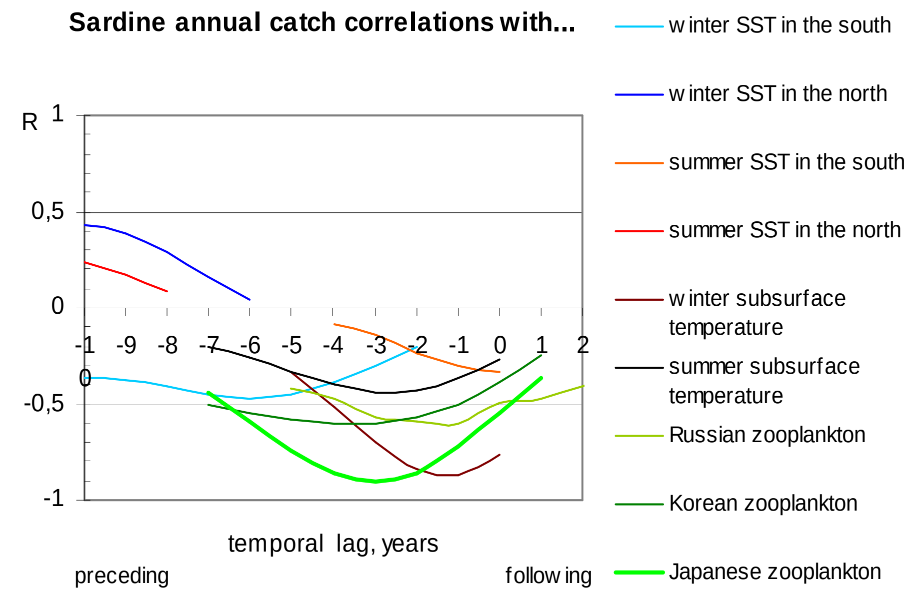
Annual catch correlates well with zooplankton biomass in the Japanese zone (positive, lag 2 years) and in the Russian zone (positive, lag 1 year).

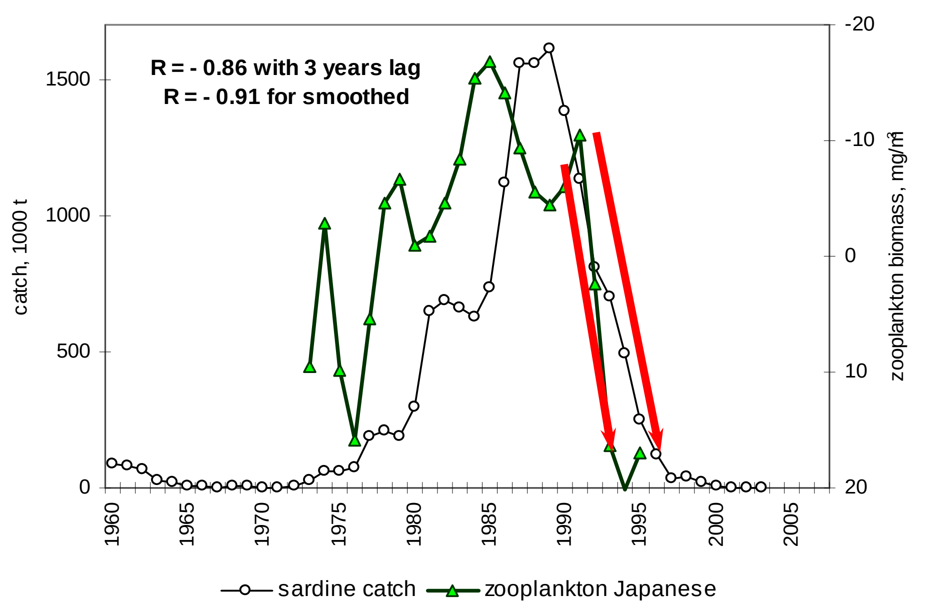
Both lags are caused by the age of spawning and mass fishery for saury (+2).
The lag for the Russian zone is shorter obviously because of elder (+1) fish on feeding grounds in the Russian zone.

Rise of zooplankton abundance in the Japanese zone in 1991-1993 and in the Russian zone in 1993-1996 (after SST rising in 1986-1989) became the reason for the saury stock and catch increase in 1994-1997.

The regime shift of the late 1990s has no visible consequences for the saury.

Japanese sardine:



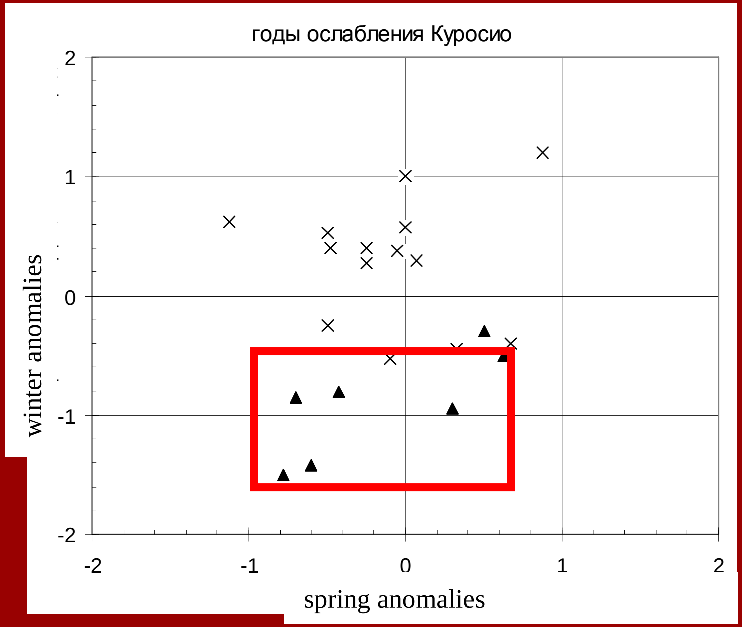


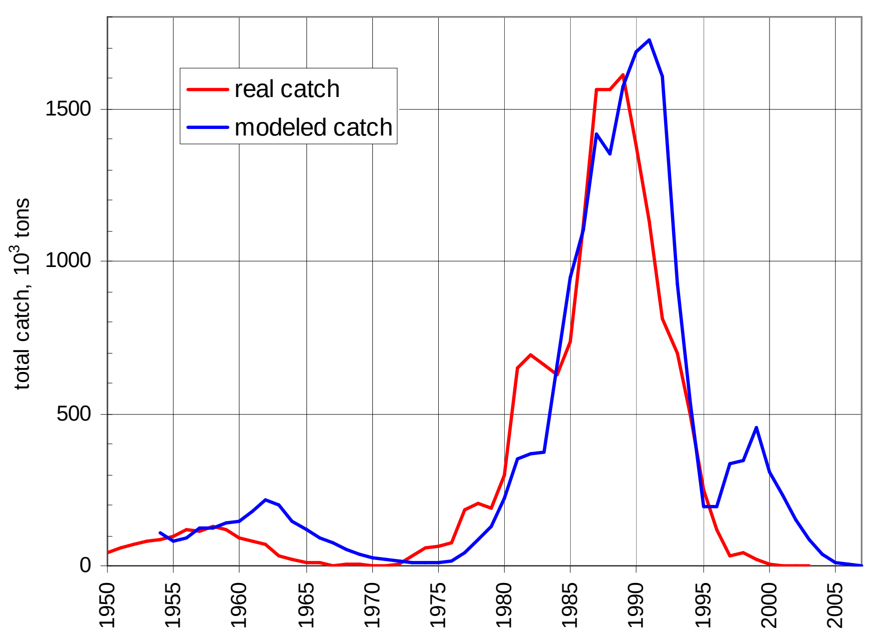
The sardine annual catch has no strong positive correlations with any environmental parameter, separately. In opposite, zooplankton biomass correlated negatively with the sardine catch, with temporal lag corresponding to the age of mass sardine fishery.

It means that the sardine influence negatively on zooplankton (grazing?) or both components depend on a common reason.

Both components (sardine and zooplankton) had sharp decreasing in the early 1990s.

Japanese sardine:





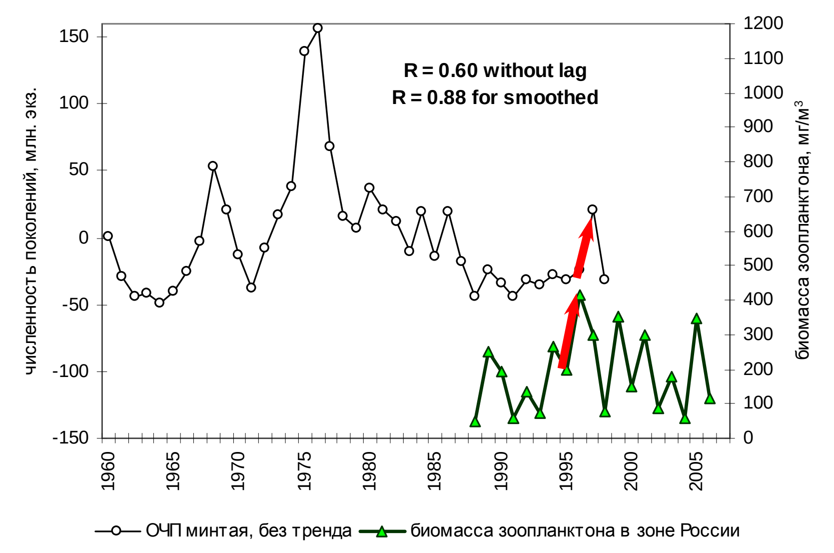
Cushing match/mismatch mechanism can be used for understanding of sardine fluctuations. We suppose that the timing of sardine larvae hatching is determined by winter SST anomaly in the southern Japan Sea, and the timing of spring plankton bloom – by spring SST anomaly. In the second half of XX Century, the sardine reproduction was successful in the years when both winter and spring SST anomalies were negative. Their ratio changed to mismatch in the late 1980s and continued to be unfavorable for sardine reproduction after the regime shift of the late 1990s.

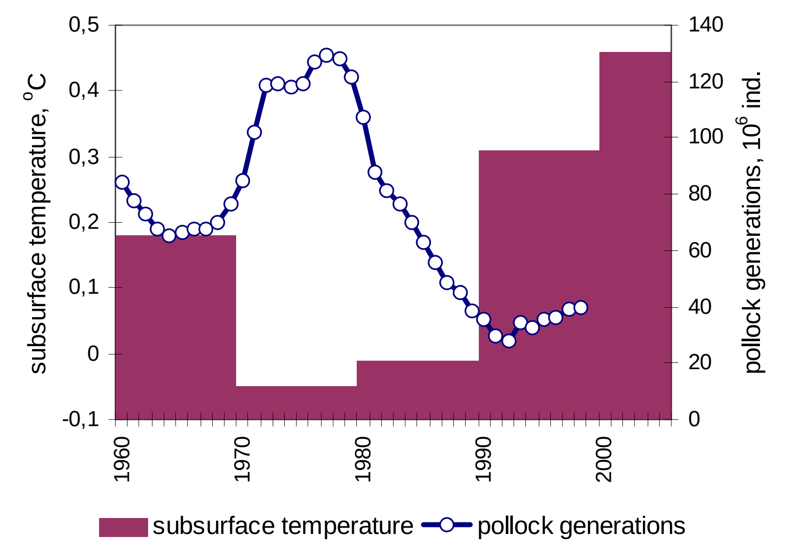
Thus factor of winter and spring anomalies match/mismatch was used as the component of multiple regressive model:

$$S_j = \Sigma_{i=3,4,5,6} [K * S_{j-i} * (f + k_W T_{W(j-i)} + k_M M_{(j-i)} + k_D S_{j-i}) * (1-m)^i]$$

that accounts number of producers (S_{j-i}), their density, annual mortality (m) and two environmental factors (T_W — winter SST at spawning grounds; M — parameter of match/mismatch); f, k_W, k_M, k_D and K – empirical constants

Walleye pollock (generations abundance):



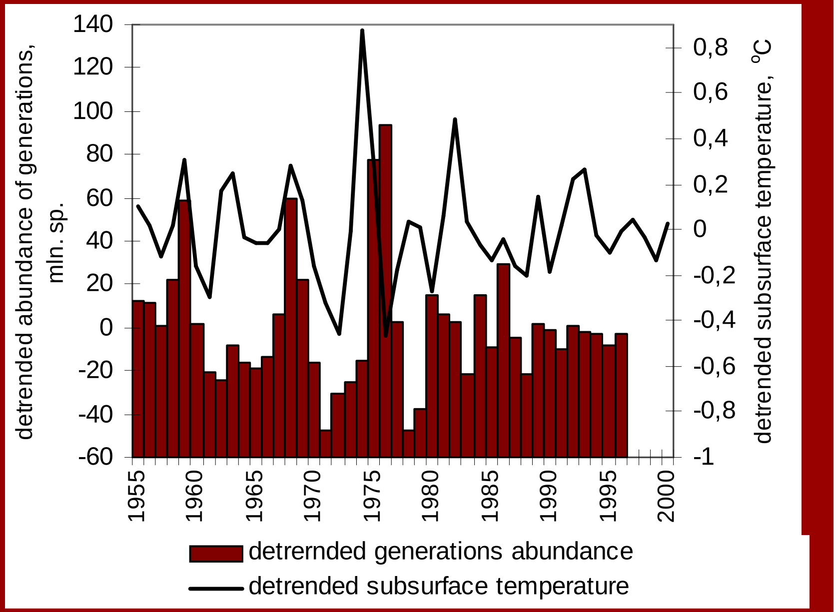


The pollock generations abundance has close formal relation with the zooplankton biomass in the Russian EEZ (positive, lag 0-1 years). However, this result is not accurate because the number of comparable data is insufficient.

In the decadal scale, the pollock generations correlate negatively with the subsurface temperature, that could be a result of ecosystem reconstructions because of competitive relations between pollack and warm-water predators in “warm” years.

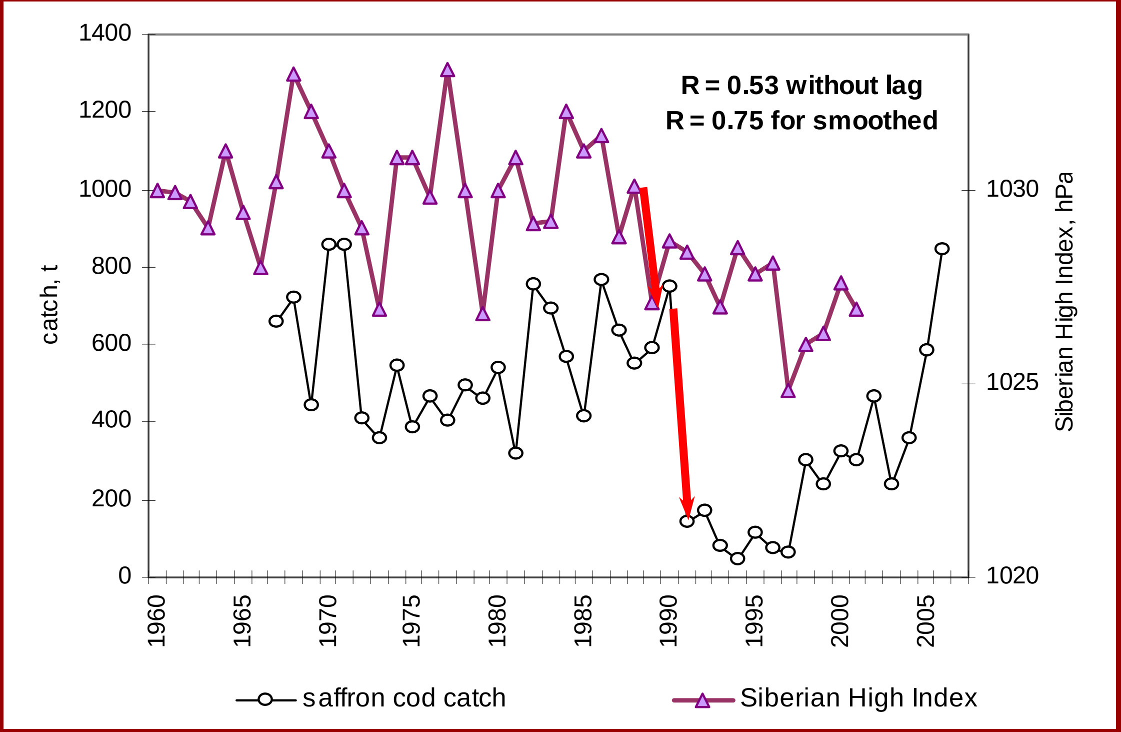
After removing decadal trends, weak positive correlation is revealed between the generations abundance and subsurface temperature, that confirms the positive relation with zooplankton abundance (the mechanism of larvae survival is possibly responsible).

Thus, pollock abundance increasing in the mid 1990s after water temperature rising was weak and followed by its decreasing.



Saffron cod:

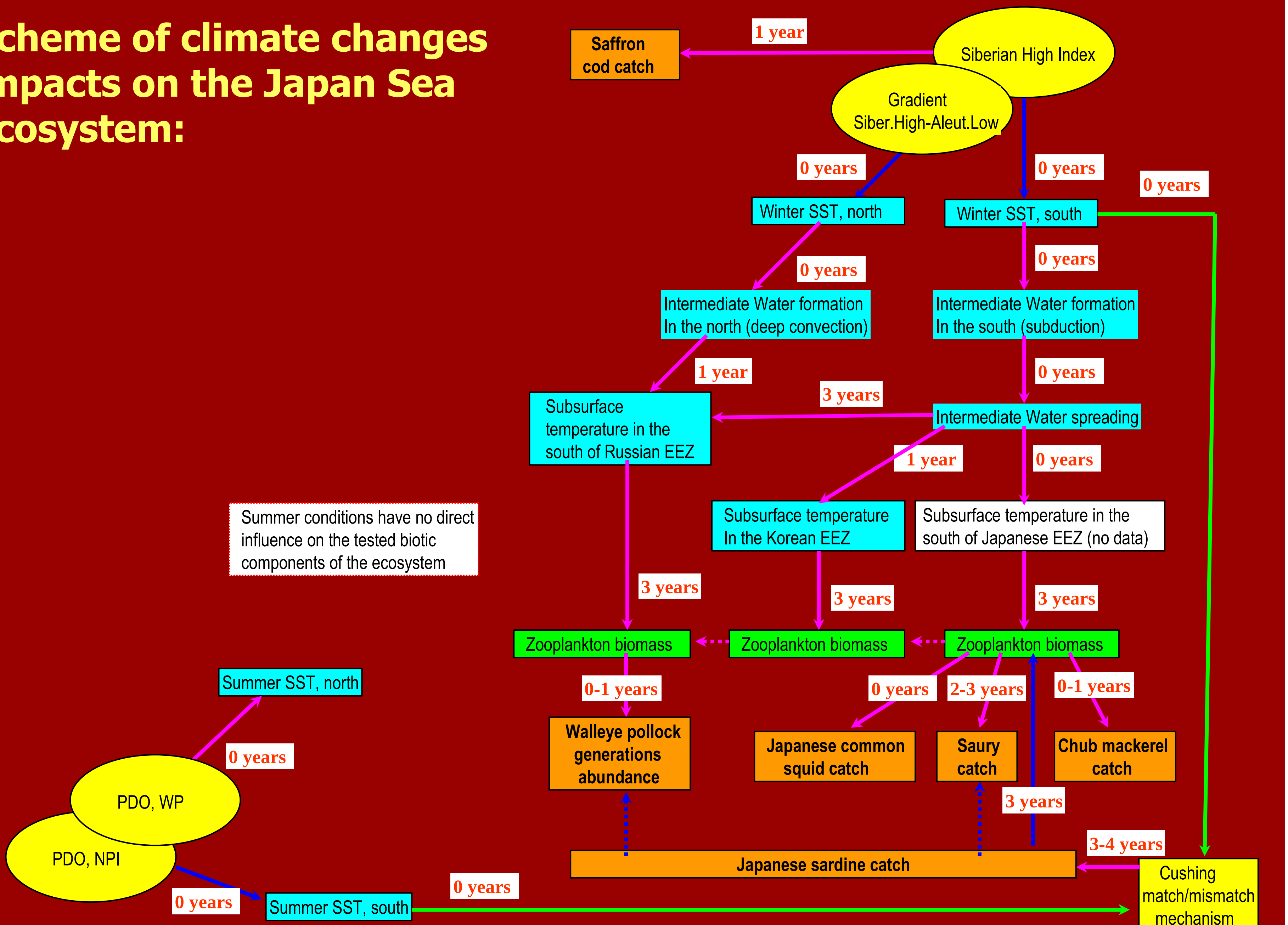
Annual catch of saffron cod correlates well directly with the Siberian High index (positive, 1 year lag). For coastal areas, this index can be used as the measure of climate severity, including sea ice development. So, the more severe winter, the more abundant population.



The saffron cod spawns only in the period of water temperature below zero, under sea ice usually. Its period of spawning is longer in the severe winters, so its reproduction is more successful. The temporal lag 1 year corresponds to the age of mass fishery of the saffron cod (1+).

The saffron cod catch decreased sharply in 1990-1991 after SHI decreasing in the late 1980s, but increased again in the period of winter warming relaxation in early 2000s.

Scheme of climate changes impacts on the Japan Sea ecosystem:



Saffron cod catch

1 year

Siberian High Index

Gradient Siber.High-Aleut.Low

0 years

0 years

0 years

Winter SST, north

Winter SST, south

0 years

0 years

Intermediate Water formation In the north (deep convection)

Intermediate Water formation In the south (subduction)

1 year

0 years

3 years

Subsurface temperature in the south of Russian EEZ

Intermediate Water spreading

1 year

0 years

Summer conditions have no direct influence on the tested biotic components of the ecosystem

Subsurface temperature In the Korean EEZ

Subsurface temperature in the south of Japanese EEZ (no data)

3 years

3 years

3 years

Zooplankton biomass

Zooplankton biomass

Zooplankton biomass

Summer SST, north

0-1 years

0 years

2-3 years

0-1 years

0 years

Walleye pollock generations abundance

Japanese common squid catch

Saury catch

Chub mackerel catch

PDO, WP

PDO, NPI

3 years

3-4 years

Japanese sardine catch

0 years

0 years

Summer SST, south

Cushing match/mismatch mechanism

Conclusions:

Shift to winter warming in the late 1980s had strong consequences for the Japan Sea ecosystem:

driving reason was winter monsoon weakening that caused:

- winter SST **increasing** synchronously
- subsurface temperature **increasing** with lags 0-3 years
- zooplankton biomass **increasing** with lags 3-6 years
- zooplanktophages fish and squid populations **increasing** and catch rising with lags 0-3 years
- winter and spring thermal conditions mismatch synchronously
- sardine population **decreasing** and catch decline with lag 3-4 years
- temporary **increasing** of the walleye pollock population with further **decreasing**
- saffron cod population **decreasing**, with further **increasing** after the warming relaxation

Shift to summer warming in the late 1990s had weak consequences for biotic components:

driving reason was summer monsoon weakening that caused:

- summer SST **increasing** synchronously
- winter and spring thermal conditions mismatch (because of winter warming relaxation)

Generally, the regime shifts to warming make physical conditions of the Japan Sea more similar to subarctic ones, and its ecosystem became more effective, but commercial productivity decreases.

The End